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14. ABSTRACT
This report describes the findings and products from F496200110214. We have maintained two simultaneous thrusts with this effort. Our first thrust has involved theoretical development so that we may capture the foundational elements associated with distributed training and distributed teams. Our second thrust has involved empirical examination of the complex mix of factors associated with distributed training. In short, we have explored the fundamental issues in knowledge acquisition and cognitively diagnostic assessment to determine how to best train the knowledge foundational to distributed training. Our overall goal is to provide the foundation on which we can design tools capable of diagnosing competencies associated with complex task performance for individuals and teams, but deliverable via distributed training systems. In this brief report we provide an overview of our project. We first describe our accomplishments in Year One that formed the foundation for our subsequent efforts and follow this with a brief review of our objectives and accomplishments for Year Two and Year Three. Based upon these findings and accomplishments, we then provide a summary of the benefits of this research to the overall AFOSR Mission.

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FINAL Report

Air Force Office of Scientific Research
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Integrating Knowledge Acquisition and Measurement Strategies
in Adaptive Distributed Training Systems

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PROJECT OBJECTIVES AND SUMMARY

Because the military is increasingly relying on geographically distributed systems using technology-mediated interaction, it is critical that we understand the cognitive processes affected by distributed interaction (at the inter- and intra-individual level), the specific conditions affecting them, and how training can be best delivered for such environments. Given the impending need to better understand these issues, our ultimate objective is to, not only understand the complex nature of distributed training for Air Force operations, but also identify the support tools needed to optimize training designed for distributed systems. Towards that end, our objectives for this 3-year project revolve around investigation of:

1) The feasibility and utility of cognitively diagnostic assessment in distributed training;
2) The identification of the learning outcomes associated with distributed training and the individual differences which may impact these outcomes; and,
3) The types of system augmentation techniques that best mediate training success when presented with differing task and individual characteristics and delivered on distributed training systems.

We have maintained two simultaneous thrusts with this effort. Our first thrust has involved theoretical development so that we may capture the foundational elements associated with distributed training and distributed teams. Our second thrust has involved empirical examination of the complex mix of factors associated with distributed training. In short, we have explored the fundamental issues in knowledge acquisition and cognitively diagnostic assessment to determine how to best train the knowledge foundational to distributed training. This has allowed us to gain a better understanding of how knowledge acquisition is related to knowledge application in the context of distributed training and distributed teams.

Our overall goal is to provide the foundation on which we can design tools capable of diagnosing competencies associated with complex task performance for individuals and teams, but deliverable via distributed training systems. In this brief report we provide an overview of our project. We first describe our accomplishments in Year One that formed the foundation for our subsequent efforts and follow this with a brief review of our objectives and accomplishments for Year Two and Year Three. Based upon these findings and accomplishments, we then provide a summary of the benefits of this research to the overall AFOSR Mission. Due to page limitations, we only abstract our work in this document. For full reprints of all described manuscripts produced with this grant, please contact, the Principal Investigator, Dr. Eduardo Salas.

THEORETICAL AND PRACTICAL ISSUES ASSOCIATED WITH ADL RESEARCH

Year One –Accomplishments and Key Findings

1. We first identified a testbed appropriate for investigation of the factors critical to distributed training and distributed teams. Specifically, our goal was to identify a testbed capable of eliciting and capturing individual and team behaviors associated with human information processing and resulting individual and team decision making. Thus, we focused on identifying the research tool that would provide the environment to investigate individual and team cognition along with critical team behaviors. We adopted a complex distributed team training testbed (DDD synthetic task) specifically designed as a low-fidelity simulation that allows basic issues to be investigated in a complex, yet controlled, setting.

2. We next designed, developed, and tested measurement protocols within the context of the chosen testbed (i.e., the DDD synthetic task). Specifically, to strengthen the base on which we would investigate distributed training, our goal was to devise measures designed to tap individual and team task-relevant knowledge.

3. We additionally developed a laboratory environment capable of conducting research in distributed learning environments. Specifically, our "Consortium for Research in Adaptive Distributed Learning Environments" (CRADLE) addresses the increasingly critical needs associated with instruction in adaptive distributed learning environments (ADL). Through partnerships with multiple research institutions, our overall goal was to create an environment that allows us to develop a fuller understanding of the learning process when ADL environments are utilized.

4. In addition to meeting the aforementioned objectives we also completed the following: (1) conducted a review of distributed learning research that identifies the emerging themes in distance and distributed learning; and, (2) developed a theoretical framework of knowledge acquisition in adaptive distributed learning environments.

Year One - Key Findings and Relevant Products

Theoretical Work

Salas, E., Kosarzycki, M. P., Burke, C. S., Fiore, S. M., & Stone, D. L. (2002). Emerging themes in distance learning research and practice: Some food for thought. *International Journal of Management Reviews, 4,* 135-153.

With the rapid spread of distance learning as a medium for delivering instruction, the practice of distance learning has outpaced research. This article describes major themes identified in a review of selected research articles published in the past five years. Themes include the following: definitions of distance learning and why it should be studied, identification of the major learning theories on which research is based, how collaboration can be achieved via distance learning, the role that learner characteristics play in the success of distance learning systems, and issues related to measuring the effectiveness of distance learning. The authors conclude that more research is needed to identify critical success factors for distance learning.

Empirical Work

Fiore, S. M., Cuevas, H. M., Scielzo, S., & Salas, E. (2002). Training individuals for distributed teams: Problem solving assessment for distributed mission research. *Computers in Human Behavior, 18,* 125 - 140.

In this paper we describe an effort investigating the feasibility and utility of cognitively diagnostic assessment of problem solving when training for distributed team tasks. We utilized computer-based knowledge elicitation methods to assess both relational problem solving, requiring the semantic integration of concepts, and dynamic problem solving, requiring the ability to integrate and apply these concepts. Additionally, we addressed how metacognitive processes interact with learning outcomes when training for complex synthetic task environments. We find first, that multiple methods of assessing problem solving performance are diagnostic of knowledge acquisition for a complex synthetic team task, and second, that general metacomprehension predisposition is related to metacomprehension accuracy in synthetic task environments.

Supplemental Publications

Fiore, S. M., Salas, E., & Bowers, C. A., (2001). Attitudes, behaviors, and cognition in distributed teams: The effect of team opacity on process and performance. *Proceedings of the 45th Annual Meeting of the Human Factors and Ergonomics Society*, 382-386. Santa Monica, CA: Human Factors and Ergonomics Society.

Year Two – Objectives and Accomplishments

Following our foundational efforts in Year One, in Year Two our objectives involved theoretical and empirical thrusts centered on distributed learning and training for complex team tasks. The objective for our empirical thrust involved understanding the instantiation and development of the knowledge structures for complex tasks when distributed learning systems are utilized. More specifically, the issue is how knowledge is integrated, a key component of the development of expertise (see Glaser, 1989). We have pursued this so that we could understand how to train for knowledge integration at the individual level and the team level (e.g., team coordination). Simultaneous to this we have been investigating the individual differences that may mediate these factors. This allows us to determine the predictive utility of particular aptitudes and how they may influence learning and performance for complex team tasks.

To explore this issue our empirical work has involved investigations of the issues outlined in our Constructive Cognitive Activities Framework (Figure 1), specifically studies of:
(1) The manner in which multi-sensory training alters cognitive processes;
(2) How individual differences impact and are impacted by learning in complex task environments;
(3) The methods necessary for knowledge acquisition in complex tasks.
(4) The development and evaluation of a testbed designed to train team competencies for a complex distributed team task; one that trains strategies and metacognitive processes.
(5) The testing of a working memory battery developed by the AFOSR "LAMP" program.
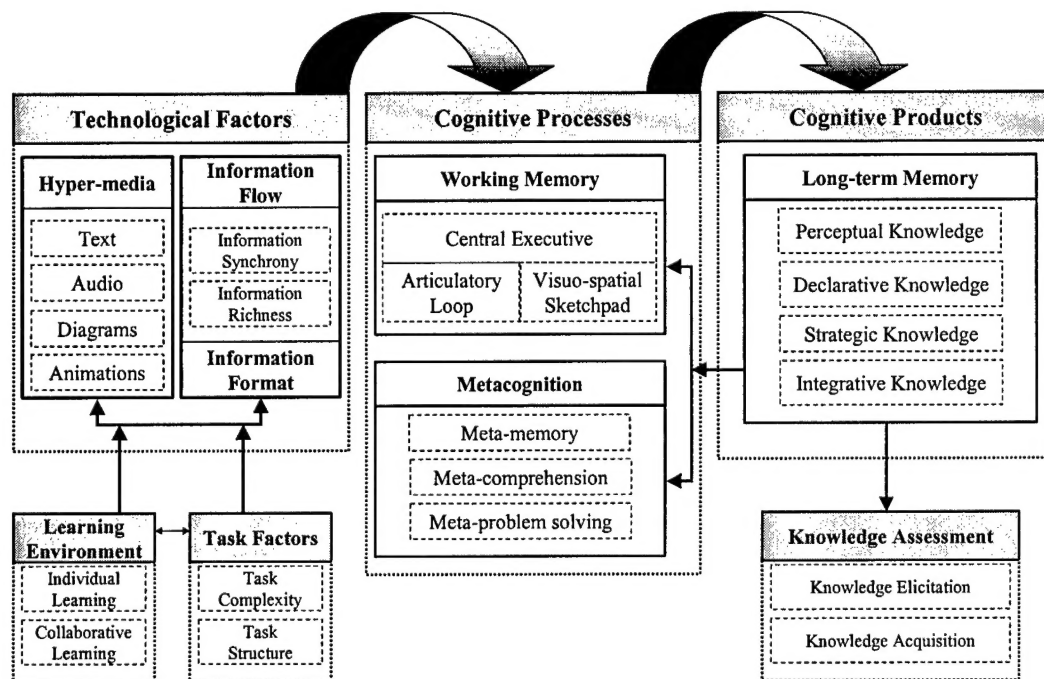

Figure 1. Constructive cognitive activities framework.

To meet the objectives of our theoretical thrust we have proceeded along two tracks, one focused on the present day issues with respect to distributed training, and the other focused more towards the future and the process issues associated with team interaction.

(1) The first portion of our theoretical work involved an investigation of distributed learning as it is understood and used in organizations today (Kosarzycki, Salas, DeRoun, & Fiore, 2003) along with the preparation of an edited volume on Adaptive Distributed Learning environments (Fiore & Salas, in preparation).

(2) The second portion of our work involved the development of an understanding of team process and performance associated with team interaction in general (Salas & Fiore, 2004) and distributed interaction in particular (Cuevas, Fiore, Bowers, & Salas, 2004; Fiore, Salas, Cuevas, & Bowers, 2003).

Year Two - Key Findings and Relevant Products

Theoretical Work

Salas, E. & Fiore, S. M. (Eds.) (2004). *Team cognition: Understanding the factors that drive process and performance.* Washington DC: American Psychological Association.

The purpose of this volume is to provide an avenue with which researchers from a diverse array of fields can present their theories and findings on team cognition in one integrated volume. As such, chapters were written by a recognized leader within their own discipline and allowed them to discuss their research in the context of a broad-based approach. Thus, this book allows researchers from differing disciplines to be brought up-to-date on both theoretical and methodological issues surrounding team cognition. Our overall goal with this volume is to illuminate team cognition through discussion of the many approaches that have been utilized in order to converge on a better understanding of this relatively amorphous concept.

Fiore, S. M., Salas, E., Cuevas, H. M. & Bowers, C. A. (2003). Distributed coordination space: Toward a theory of distributed team process and performance. *Theoretical Issues in Ergonomic Science, 4, 3-4,* 340-363.

In this paper we discuss a theoretical framework designed to elucidate the many issues surrounding distributed team performance, emphasizing how work characteristics associated with such teams may alter both the processes and the products emerging from distributed interaction. We suggest that distributed team performance can best be understood through conceptualization of a coordination space within which distributed interaction occurs over time and distance. Our goal is to take a socio-technical approach to distributed team research so that we can explicate both the cognitive consequences of a lack of co-location as well as the social consequences affecting interaction and team development when work is technology-mediated. Our overall objective is to present a framework of "distributed coordination" such that the principles most appropriate for distributed team performance can be developed.

Cuevas, H. M., Fiore, S. M., Salas, E., & Bowers, C. A. (2004). Virtual teams as socio-technical systems. In S. H. Godar & P. Ferris (Eds.), *Virtual and collaborative teams: Process, technologies, and practice* (pp. 1-19).

In this chapter, we adopt a sociotechnical systems approach to understand the challenges faced by members of an organizational unit that is not constrained by geographical, temporal, organizational, and/or national boundaries. Specifically, we examine distributed team performance within the context of an open sociotechnical system, highlighting the effects that the technological subsystem (e.g., collaborative information technology) and external environmental factors (e.g., lack of co-location) have on the personnel subsystems (i.e., distributed team members) within the organization. The organizational psychology literature on group productivity, motivation, and shared mental models is reviewed to understand team performance within the context of distributed environments, and in order to offer guidelines and interventions for organizational practice.

Kosarzycki, M. P., Salas, E., DeRouin, R., & Fiore, S. M. (2003). Distance learning in organizations: A review and future needs. In D. Stone (Ed.), *Advances in human performance and cognitive engineering research, Volume 3* (pp. 69 – 98). Amsterdam: JAI Press, Elsevier Science.

Many organizations have implemented distance-learning (DL) courses and programs as an economical, efficient way to deliver training. The purpose of this chapter is to summarize some of the major considerations that are associated with distance-learning programs. We describe a number of the issues surrounding DL, ranging from how organizations use DL to the differing forms of training being delivered and how organizations are reacting to DL. We close with a discussion of issues in practice and suggest directions for future research.

Empirical Work

Fiore, S. M., Cuevas, H. M., Scielzo, S., & Salas, E. (in press). Metacognitive bias in complex task training: Influence of verbal ability in performance prediction accuracy. To appear in S. M. Fiore & E. Salas (Eds.), *Where is the learning in distance learning?: Towards a science of distributed learning and training.* Washington DC: American Psychological Association.

In this chapter we address how metacognitive processes interact with learning outcomes when training for complex task environments. We report the findings from two different studies that show strikingly similar patterns of performance with respect to differences in verbal ability, metacognition, and performance. Participants' metacognitive bias scores (differences between prediction and performance) were negatively related to performance and the difference in bias scores between high and low verbal ability participants was greater with more complex measures of knowledge acquisition. Furthermore, these bias scores consistently revealed that low verbal ability participants were overestimating their performance while high verbal ability participants were either underestimating their performance or were very accurate in predicting their performance (i.e., bias scores near zero). Results are discussed in the context of metacognition in general and adaptive training for complex tasks in particular.

Fiore, S. M., Cuevas, H. M., Scielzo, S., & Salas, E. Metacognition and multimodalities: Altering processes and products in distributed learning. *Manuscript in preparation.*

In this experiment we investigated the degree to which metacognition can be altered by hypermedia training manipulations. We looked at how the presentation of identical information using differing modalities might alter meta-comprehension processes and subjective workload. We hypothesized that that the subjective experience (encoding process) may be altered when attempting to learn via the differing presentation manipulations. As such, metacomprehension may vary across these modalities dependent upon the degree to which participants perceive they have successfully retained and/or understood the material. Because audio presentation is a less typical manner of information acquisition, participants may find it more challenging and be less confident in their understanding of the material. Although both text and audio are thought to be processed within the articulatory loop, our argument is that they will differently interact with

metacognitive processes (e.g., central executive processes) thus altering overall accuracy in metacognition. Thus, participant ratings of metacomprehension may be lower and their assessment of workload higher, when material is presented auditorially. These predictions center, not on knowledge acquisition, but on the learner's perception of their knowledge acquisition. Although there may be little or no difference in actual performance on tests of comprehension dependent upon modality, the atypical nature of the encoding experience may alter metacomprehension prediction accuracy.

Scielzo, S., Fiore, S. M., Cuevas, H. M., & Salas, E. (2004). Diagnosticity of mental models in cognitive and metacognitive processes: Implications for synthetic task environment training. In S. G. Schiflett, L. R. Elliott, E. Salas, & M. D. Coovert (Eds.), *Scaled worlds: Development, validation, and application* (pp. 181-199). Aldershot, UK: Ashgate.

In this chapter we discuss the utility of mental model assessment when training in synthetic task environments (STE). We discuss both cognitive and metacognitive processes within the context of knowledge acquisition and describe the theoretical issues surrounding these factors when training for complex team tasks. We additionally report a portion of our research findings in order to illustrate how mental model measurement can be used in cognitively diagnostic assessment. This study used an automated training system, designed to instruct participants to interact within a synthetic task environment for military command and control. A computer-based knowledge test was developed to assess differing components of knowledge critical to performance in this STE and a computerized knowledge elicitation method was used to assess the development of participants' mental models when training for this task. Additionally, metacognitive processes were measured prior to, and following, the STE knowledge assessment battery. We show how mental model accuracy is indicative of both accuracy in metacognitive processes as well as knowledge acquisition for STE training. We conclude with a discussion of the implications for training research when using STEs.

Supplemental Work

Cuevas, H. M., Fiore, S. M., Salas, E., & Bowers, C. A. (2002). A macroergonomic approach to distributed team performance. *Proceedings of the 46th Annual Meeting of the Human Factors and Ergonomics Society*, 1335-1339. Santa Monica, CA: HFES.

Cuevas, H. M., Fiore, S. M., Salas, E., & Bowers, C. A. (in press). Virtual teams as sociotechnical systems. To appear in M. Khosrow-Pour (Ed.), *Encyclopedia of Information Science and Technology, Volume I-V.* Hershey, PA: Idea Group Publishing.

Fiore, S. M., Cuevas, H. M., Salas, E. & Schooler, J. W. (2002). Distributed teams and distributed memory. *Proceedings of the 46th Annual Meeting of the Human Factors and Ergonomics Society,* 398-402. Santa Monica, CA: HFES.

Year Three – Objectives and Accomplishments

In Year Three our objectives continued to involve theoretical and empirical thrusts centered on distributed learning and training with an increasing emphasis on knowledge application for complex tasks when distributed learning systems are utilized (Cuevas, 2004). Simultaneous to this we have continued our work with knowledge acquisition but have broadened it to consider additional methods that may accelerate the knowledge integration process when training for complex tasks (Cuevas, Scielzo, & Fiore, in preparation; Kring, 2004). This has involved:

1. The development of experiments to investigate characteristics of the training to determine how instructional science strategies may be adaptable to multiple training needs.
2. Examination of how individual differences in trainee aptitudes may interact with the design components of computer-based training on complex tasks.
3. The team process factors driven by team cognition and which may alter team coordination.

Specifically we build upon the research assessing the degree to which distributed teams and distributed training alter individual and team process and performance. We take a multi-pronged approach to converge on a fuller understanding of the issues surrounding team training for complex tasks (e.g., metacognitive processes during learning; developing integrated knowledge via concept mapping) along with the task and environmental characteristics (task complexity, high workload) that influence cognitive processes in complex task domains (e.g., memory – dependent actions) (Cuevas, Fiore, & Kring, in press; Fiore, Cuevas, Schooler, & Salas, in press). We have similarly considered team cognition issues both within and across teams (Fiore, Jentsch, Bowers, & Salas, 2003). We continued with assessing how these factors may uniquely tax individual differences in aptitude (e.g., verbal ability) in order to determine how differing training manipulations may scaffold that training (Cuevas, Fiore, Bowers, & Salas, 2004; Cuevas, Scielzo, & Fiore, in preparation).

Last, we began work on a technology transfer component of our research effort. This involved the creation of a detailed instructional manual describing the methodology employed in the development of training and testing modules used to diagnose differing components of knowledge acquisition (Scielzo, Cuevas, & Fiore, 2004). We describe via narrative and diagrammatic presentation the manner in which our experimental system was developed so laboratories and government entities conducting similar research can use this methodology.

Year Three - Key Findings and Relevant Products

<u>Theoretical Work</u>

Bowers, C. A. & Salas, E. (Eds.). (in press). *Teams and technology.* Washington, DC: American Psychological Association.

One of the most striking changes in modern work life has been the dramatic increase in the importance of teamwork. As the nature of work grew more technical and complex, it became apparent that the "one person, one job" approach to working was badly outdated. Companies scrambled to identify ways to foster teamwork in businesses throughout the world. Scientists scrambled to learn about the nature of teamwork while managers wrote (and bought) hundreds of books on the subject. The impact has been that "teaming" is now an essential part of how almost every company in the world does business, and that teamwork is considered a core competency for most employees. The interest in teamwork appears to be fading, somewhat, because most companies have it "Figured out." We suggest, however, that this is just a calm before another storm involving teams. The next challenge to teamwork in organizations is to cope with the effects of the many technologies that are being acquired by businesses. This is no small matter. Most of what we know about teamwork involves groups of people sitting around a table. However, modern teams rarely sit around tables anymore. 21st century teamwork takes place through e-mail, video conferences, collaborative groupwork systems and other technologies. Furthermore, teammates are not necessarily human. Employees now get advice from artificially intelligent systems that function as "virtual team members." In some cases, the machine is actually "the boss." Organizations are woefully unprepared to integrate these technologies into their teams. As such, in this volume we distill the best and most current scientific knowledge and combine it with practical "lessons learned" from organizations using these systems.

Fiore, S. M. & Salas, E. (Eds.). *Where is the learning in distance learning?: Towards a science of distributed learning and training.* Edited volume in preparation. Washington, DC: American Psychological Association.

Modifications to industrial operations and rapid advances in technology have created an unparalleled demand for training. Simultaneous to this has been a rapid advance in technology for the delivery of training. Because of this, traditional "classroom" learning and training approaches have been increasingly supplanted by distance-learning efforts. We use the term "Distributed Learning" to generally describe training taking place while the student/trainee is geographically isolated from either the instructor or their peers. Although this technology offers tremendous promise, and is already being widely used both in academia and industry (e.g., over a billion dollars is typically spent on non-classroom delivery of training annually), the scientific and pedagogical implications of such instruction are unclear. The purpose of this volume is to assemble leading researchers whose work directly bears on the issues critical to our understanding of the theoretical and methodological implications surrounding distributed learning.

Fiore, S. M., Cuevas, H. M., Schooler, J. & Salas, E. (in press). Cognition, teams, and team cognition: Memory actions and memory failures in distributed team environments. To appear in E. Salas & C. A. Bowers (Eds.), *Teams and technology*. Washington, DC: American Psychological Association.

The implementation and/or use of distributed teams as a definable organizational unit has dramatically increased the structural complexity of teams in organizations. Adopting a sociotechnical systems approach, we attempt to demonstrate how theories from cognitive science can be used to explore the unique challenges emerging from this new organizational structure. Specifically, we focus on the memory actions that are foundational to effective task performance, particularly in these complex operational environments, and highlight how the team opacity arising from distributed interaction can impact team cognition, potentially leading to memory failures. We conclude with a proposed framework designed to facilitate our understanding of memory failures in complex operational environments, and offer guidelines for organizational practice.

Fiore, S. M., Jentsch, F., Bowers, C. A., & Salas, E. (2003). Shared mental models at the intra- and inter-team level: Applications to counter-terrorism and crisis response for Homeland Security. *Proceedings of the 47th Annual Meeting of the Human Factors and Ergonomics Society*, 439-443. Santa Monica, CA: Human Factors and Ergonomics Society.

Critical to meeting the needs arising from an increasing emphasis on homeland security is a fuller understanding of how to maximize the interactions among a diverse group of people and organizations. The complicating issue is the need to coordinate experts and teams of experts from differing disciplines. From a practical standpoint, because of the multidisciplinary requirements for effective homeland security, it is imperative that methodologies that can foster inter-individual (i.e., within team) and inter-organizational coordination (i.e., across departments or organizations) be investigated. From a theoretical standpoint, the operational concepts that drive the investigation and development of such methodologies must be identified. We suggest that the concept of shared mental models, arising out of research in the cognitive and organizational sciences, can be utilized in a program of research that explores the methods and tools to facilitate coordination in homeland security. Shared mental models can be applied to help our understanding of coordinated behavior at both the team level and the organizational level and, in this paper, we illustrate the relevance of this construct to both counter-terrorism operations and crisis response. We first discuss the shared mental model construct and follow this with a brief description of sample applications.

Fiore, S. M., Cuevas, H. M., & Salas, E. (2003). Putting working memory to work: Integrating cognitive science theories with cognitive engineering research. *Proceedings of the 47th Annual Meeting of the Human Factors and Ergonomics Society*, 508-512. Santa Monica, CA: Human Factors and Ergonomics Society.

Human factors research has long included discussions of the importance of mental models when understanding human-human interaction and human-system interaction. Additionally, a small

number of researchers in the field have included theories of working memory and related constructs in their research approaches. Nonetheless, little if any research has acknowledged the connection between these two very important constructs arising out of the cognitive sciences. In this paper we discuss recent theoretical and empirical developments on working memory from cognitive psychology and cognitive neuroscience and relate these to our understanding of mental models. We show how the connection between these two concepts can facilitate a deeper understanding of issues associated with cognitive engineering and decision making research.

Scielzo, S. & Fiore, S. M. A two-stage model of multimedia learning: Implications for multimedia design. *Manuscript in preparation.*

The advances of multimedia technology supporting computer-based learning environments are such that the research necessary to understand the underlying mechanisms of optimal knowledge acquisition did not coalesce into a more integrated and unified approach. In order to assist multimedia research integration, this paper first reviews various factors from the computer-based training and learning literature that most impact knowledge acquisition while introducing the necessary operationalization of various concepts to help tease out some important learning effects generated by the use of multimedia. Second, this paper proposes a two-stage model of multimedia learning based on classical theoretical models and recent results from computer-based multimedia research using specific terminology. Finally, stemming from this model, a series of propositions are brought forth to foster empirical evaluation of the model while providing guidelines for computer-based multimedia design.

Technical Work

Scielzo, S., Cuevas, H. M., & Fiore, S. M. (2004). *Dynamic Distributed Decision-Making: Development of mock-up scenarios for synthetic task environment training* (Technical Report for the Air Force Office of Scientific Research, prepared under Grant Number F49620-01-1-0214). Orlando, FL: University of Central Florida.

In this technical report, we first report the methodological procedures used to develop our training tutorial, composed of three modules (general information, procedural training, team training); and second, we report the development of our knowledge test, composed of a declarative and an integrative section. Specific to the training, Module 2 of the tutorial contains several videos and 'mock-up' scenarios designed to mimic the environment of the Dynamic Distributed Decision-making (DDD) command-and-control synthetic task. The main goal of using various mock-up scenarios in our training was to give hands-on experience aimed at refining trainees' procedural skills. As such, particular care was devoted to artificially render the original synthetic task environment (STE). The mock-up scenarios were developed with two design characteristics: 1) Mock-up scenarios faithfully reproduced the original environment for accurate transfer of procedural skills; 2) Visual feedback was incorporated in the mock-up scenarios in order to guide the trainee into effectively learning specific procedures. In the knowledge test, particular attention was given to the 'integrative' portion, consisting of animated videos of specific DDD team scenarios. Those scenarios were developed to test trainees'

knowledge transfer of the game to team related questions. For both the training tutorial and the integrative portion of the knowledge test, Microsoft® PowerPoint® 2000 and TechSmith® SnagIt® were employed. The two software programs were used in combination to integrate screen captures and video captures of the DDD environment into self-paced presentations.

Empirical Work

Cuevas, H. M., Fiore, S. M., Bowers, C. A., & Salas, E. (2004). Fostering constructive cognitive and metacognitive activity in computer-based complex task training environments (Invited paper for Special Issue on Human-Computer Interaction). *Computers in Human Behavior, 20*, 225-241.

In this paper, we describe a multi-year programmatic research effort aimed at investigating the use of interactive computer-based training technology, such as enhanced displays, to support the acquisition, development, and transfer of knowledge related to critical linkages in domain knowledge for complex task training environments (e.g., aviation, distributed decision-making). We also introduce preliminary findings from our most recent work examining the effectiveness of guided, learner-generated instructional strategies embedded within computer-based training, designed to prompt learners to monitor their comprehension and mindfully engage in constructive cognitive and metacognitive activities. We review the successive iterations of our investigation, and, based upon the significant findings in our studies, extract a set of propositions for the design and evaluation of computer-based training programs for complex systems. These propositions will be presented in the context of the related theoretical rationale drawn from the literature and the relevant empirical support from the body of research conducted over these past three years.

Scielzo, S., Fiore, S. M., & Cuevas, H. M. Multimedia design and redundancy in complex training environments. *Manuscript in preparation.*

The present study investigated how manipulating the redundancy state (simple or complex redundancy) of multimedia-based instruction may impact knowledge acquisition, and how distinct training effectiveness measures may be best used to evaluate multimedia design principles as they apply to training for complex systems. The results show that redundancy of information, which has previously been shown to negatively impact knowledge acquisition, yielded the opposite results in our study. These results suggest that high overlay of redundant codes of information can foster knowledge retention. A similar pattern of results was found in terms of reduced cognitive load, as indicated by higher instructional efficiency achieved via the redundant training program. The discussion centers on the generalizability of principles of multimedia learning when applied to more complex training environments. Implications for multimedia design are discussed within the context of cognitive load theory.

Fiore, S. M., Scielzo, S., Cuevas, H. M., & Salas, E. Working with working memory in complex task training. *Manuscript in preparation*.

Foundational to our understanding of the successful implementation of distributed training is the investigation of the impact that individual differences in abilities have on the cognitive processes and cognitive products emerging from these environments. In order to accomplish this objective we need reliable and valid instruments to assess learners' cognitive abilities. Kyllonen and colleagues (1993, 1994) developed the Cognitive Abilities Measurements (CAM) framework to maximize the individual differences variability in performance accounted for using assessment tests. CAM is an evolution of a 4-factor model, emphasizing the significant role of individual differences in working memory capacity, information-processing speed, breadth of declarative knowledge, and breadth of procedural knowledge (see also, Kyllonen & Christal, 1989). The CAM battery can serve as a reliable, valid, and powerful tool to measure individual differences in cognitive abilities that are deemed critical for successful learning outcomes in complex task training (Kyllonen, 1993). Furthermore, of the many cognitive ability factors evaluated by the CAM battery that seem to predict individual variability in performance, working memory tests were found to be "maximally valid, that is, they correlate[d] more highly with... learning criterion[s] than any other kind of test" (Kyllonen, 1994, p. 336). Therefore, the CAM battery can be effectively utilized in our research effort to evaluate the extent to which individual differences in working memory capacity affect cognitive processes and cognitive products in distributed learning environments. Thus far we have updated CAM-4 for use in a Windows environment (from a DOS-based program). In a pilot study we have successfully used this updated battery and we are currently analyzing how these individual differences in working memory interact with complex task training.

Kring, E., D. (2004). *Improving metacomprehension and learning through graduated concept model development* (Doctoral dissertation, University of Central Florida, Orlando, 2004).

Mental model development, deeper levels of information processing, and elaboration are critical to learning.   More so, individuals' metacomprehension accuracy is integral to making improvements to their knowledge base. In other words, without an accurate perception of their knowledge on a topic, learners may not know that knowledge gaps or misperceptions exist and, thus, would be less likely to correct them. Therefore, this study offered a dual-process approach that aimed at enhancing metacomprehension. One path aimed at advancing knowledge structure development and, thus, mental model development. The other focused on promoting a deeper level of information processing, through processes like elaboration. It was predicted that this iterative approach would culminate in improved metacomprehension and increased learning.

Accordingly, using the Graduated Concept Model Development (GCMD) approach, the role of learner-generated concept model development in facilitating metacomprehension and knowledge acquisition was examined. Concept maps have had many roles in the learning process as mental model assessment tools and advanced organizers. However, this study proposes that the process of concept model building may also be an effective training tool. Where advanced organizers likely rely on recognition, concept model development requires recalling and understanding 'how' and 'why' the interrelationships between concepts exist. Indeed, central to improving

knowledge deficiencies and misunderstandings is metacomprehension, and the constructing of concepts maps is likely to improve metacomprehension accuracy and, thus, learning.

The GCMD alone condition showed a stronger indication of metacomprehension accuracy, via prediction measures, compared with the other three conditions (Control, Advanced Organizer, and GCMD with Feedback), and, specifically, significantly higher correlations than the other three conditions in declarative knowledge. Self-efficacy measures also indicated that the higher metacomprehension accuracy correlation observed in the GCMD condition was likely the result of the intervention, and not due to differences in self-efficacy in that group of participants. Likewise, the Feedback and GCMD conditions led to significantly high correlations for metacomprehension accuracy based on levels of understanding on declarative knowledge tutorial module. The Feedback condition also showed similar findings for the strategic knowledge module.

Results, however, failed to reveal any significant differences between the four conditions in mental model accuracy or performance on a knowledge assessment task. Nevertheless, results do support the relevance of accurate mental model development in knowledge assessment outcomes. Specifically, in terms of cognitively diagnostic assessment, results showed that mental model accuracy (as measured by similarity to an expert model) was predictive of knowledge acquisition. Greater similarity to an expert model led to significantly greater performance on measures of basic factual knowledge (declarative questions), and more importantly, measures assessing integration and application of task-relevant knowledge (integrative questions).

Retrospectively, two opposing factors my have led to some insignificant findings. From one side, the experimental measures may not have been rigorous enough to filter out the effect from the intervention itself. Conversely, software usability issues and the resulting limitations in experimental design worked negatively against the two concept mapping conditions and, inadvertently, suppressed effects of the intervention. Future research in the GCMD approach will likely review cognitive workload, concept mapping software design, and the sensitivity of the measures involved.

Cuevas, H. M., Scielzo, S., & Fiore, S. M. Evaluating the instructional efficiency of a guided learner-generated questioning strategy within computer-based complex training environments. *Manuscript in preparation.*

This study assessed the extent to which a guided learner-generated questioning strategy (learning check) could facilitate acquisition of task-relevant knowledge and improve the instructional efficiency (i.e., relation between perceived cognitive effort during training and testing and post-training performance) for a complex dynamic distributed decision-making task. The learning checks involved the use of a content-free question stems (e.g., "How are _____ and _____ related?"), designed to prompt trainees to actively monitor their own learning. In addition, this study also investigated the degree to which individual differences in learner aptitudes (verbal comprehension ability) interacted with the instructional strategy to impact training outcomes. In general, the results highlighted the important role of individual differences in relevant learner

aptitudes for achieving successful outcomes in computer-based training environments. Participants demonstrating high verbal comprehension ability consistently outperformed participants with low verbal comprehension ability on the knowledge assessment task. Further, results also showed that the training program's instructional efficiency was significantly greater when evaluated for the high verbal comprehension ability participants, as compared to the low verbal comprehension ability participants. In addition, incorporating the learning check strategy into the instruction also consistently yielded positive instructional efficiency scores overall. Finally, with regard to aptitude-treatment interactions, findings showed that incorporating the learning check strategy into the training significantly improved the program's instructional efficiency when examining the results for low verbal comprehension ability participants. This beneficial effect on the training program's instructional efficiency was not evident when results were examined for high verbal comprehension ability participants. Results are discussed in terms of the implications for the design of adaptive learning systems.

Cuevas, H. M., Fiore, S. M., Bowers, C. A., & Salas, E. (2004). Using guided learner-generated instructional strategies to transform learning into a constructive cognitive and metacognitive activity. *Proceedings of the 48th Annual Meeting of the Human Factors and Ergonomics Society*, 1049-1053. Santa Monica, CA: HFES.

Successful learning outcomes in learner-controlled, computer-based training environments are inherently dependent upon learners' possession of well-developed metacognitive skills, that is, how well learners are able to accurately monitor and regulate their knowledge acquisition process. The present study explored the effectiveness of embedding a guided learner-generated instructional strategy (query method), designed to support learners' cognitive and metacognitive processes within the context of computer-based complex task training. The queries were presented as "stop and think" exercises in an open-ended question format that asked learners to generate complex (high level elaboration) sentences from a list of key concepts presented in the training. In terms of cognitive processes, results showed that incorporating the query method into the training resulted in improved integration and application of task-relevant knowledge, as indicated by greater similarity to an expert model of the domain and better performance on integrative knowledge assessment requiring the integration and application of task-relevant concepts. With regard to metacognitive processes, the query method may have also assisted participants in more accurately monitoring their comprehension, as indicated by their significantly lower bias scores. Results are discussed in the context of designing adaptive learning systems.

Cuevas, H. M. (2004). *Transforming learning into a constructive cognitive and metacognitive activity: Use of a guided learner-generated instructional strategy within computer-based training* (Doctoral dissertation, University of Central Florida, Orlando, 2004).

The present study further explored the effectiveness of embedding a guided, learner-generated instructional strategy (query method), designed to support learners' cognitive and metacognitive processes in computer-based training environments. The queries were presented as "stop and think" exercises in an open-ended question format that asked learners to generate either simple

(low level elaboration) or complex (high level elaboration) sentences from a list of key concepts presented in the training. Overall, results consistently highlighted the beneficial effect of presenting participants with *low-level* elaboration queries, as compared to the no-query or high-level elaboration query conditions.

In terms of post-training cognitive outcomes, participants presented with the low-level elaboration queries generated significantly more accurate sentences, exhibited significantly more accurate knowledge organization (as indicated by greater similarity to an expert model), better acquisition of perceptual knowledge, and superior performance on integrative knowledge assessment requiring the integration and application of task-relevant concepts. Consistent with previous studies, no significant differences in performance were found on basic factual knowledge assessment. Presentation of the low-level elaboration queries also significantly improved the training program's instructional efficiency, that is, greater performance was achieved with less perceived cognitive effort. In terms of post-training metacognitive outcomes, participants presented with the low-level elaboration queries exhibited significantly greater metacomprehension accuracy and more effective metacognitive self-regulation during training.

The results of this study are discussed in terms of the theoretical implications for garnering a better understanding of the cognitive and metacognitive factors underlying the learning process. Practical implications for training design are presented within the context of cognitive load theory and the need for a multi-faceted approach to training evaluation.

Supplemental Work

Cuevas, H. M., Fiore, S. M., & Kring, J. P. (in press). Understanding memory actions and memory failures in extreme environments. *Proceedings of the Second Annual Meeting of the Society for Human Performance in Extreme Environments (HPEE)*. Orlando, FL: HPEE.

BENEFITS TO AFOSR

The benefits to AFOSR of this research effort fit within the overall mission of understanding human information processing within complex environments. Specifically, a portion of the overarching objectives of AFOSR research on human performance involve the development of models and methods associated with: (1) the cognitive factors related to the acquisition of complex skills; (2) the individual attributes impacting human performance; and, (3) team performance in complex environments. In this section we briefly highlight how the findings from this grant help AFOSR meet these objectives and follow this with an example application to Air Force operations.

Cognitive Factors Related to the Acquisition of Complex Skills

We have illustrated how distributed learning based methods of training can be used to quantify potential performance by diagnosing the cognitive factors related to skill acquisition associated with complex distributed team tasks. These findings aid the Air Force by providing the foundation on which we can understand the learning processes associated with transforming the novice to the expert as well as the training methodologies to scaffold that transformation.

- We have developed methodologies that assess one's ability to *describe* and *explain* components of one's mental models associated with a complex distributed team task.
- We have devised a dynamic measure using animated scenario vignettes. These assess one's ability to accurately combine differing knowledge components and predict future events.
- We have shown the utility of using knowledge elicitation techniques to gauge knowledge acquisition by documenting a relation between performance and accurate mental model development.
- We have documented how differing forms of information presentation (i.e., audio versus text) can alter the cognitive processes associated with training for complex tasks.
- Based upon the aforementioned methods of cognitively-based diagnoses, we have discussed how training strategies associated with knowledge acquisition and knowledge integration can be developed.
- We have developed an augmented model of multimedia learning where factors associated with differing modalities of presentation are accounted for in training outcomes for complex tasks.
- We have compiled an edited volume on distributed and distance training where leading researchers in the field discuss their theory and findings in this area.

Individual Attributes Impacting Human Performance

We have begun to identify and quantify the individual attributes related to learning and performance in complex environments. These findings aid the Air Force by providing the foundation on which to understand how to develop training systems that are adaptable to differing characteristics of learners and teams of learners. Thus, we have identified a portion of the basic issues associated with the development of systems that will account for diversity in aptitudes, skills, and knowledge.

- We have documented how verbal ability differentially influences the cognitive processes associated with predicting one's mastery of material for complex task training. Further, we have shown how the more complex the measure, the greater the inaccuracy for low verbal participants and the greater the accuracy for high verbal participants.

- We have illustrated how general predispositional traits associated with metacognition can be predictive of performance when training with synthetic team tasks
- We have begun preliminary investigation of how the working memory subcomponent of the Air Force's "Cognitive Abilities Measure" is related to performance when training for complex tasks.

Team Performance in Complex Environments

Via theoretical analyses we have articulated the critical components associated with learning and performance in distributed team tasks. These findings benefit the Air Force by providing the foundation on which to understand how the paucity of task and/or team artifacts associated with distributed interaction can influence team process and performance, and subsequently, how training programs can be devised to attenuate this impact.

- We have described how distributed interaction may alter the workload associated with team interaction and thus have a cascading effect on team coordination
- We have discussed how distributed interaction can impact the attitudinal factors associated with team process and subsequently alter team performance
- We have articulated how distributed interaction may impinge upon or alter the memory processes associated with complex team tasks and thus hinder team coordination.
- We have completed an edited volume providing an avenue with which researchers from a diverse array of fields can present their theories and findings on team cognition in one integrated volume. This book allows researchers from differing disciplines to be brought up-to-date on both theoretical and methodological issues surrounding team cognition.
- We are completing an edited volume on teams and technology where researchers discuss the many ways team process and performance is altered by technological innovation.

Sample Air Force Applications

A number of issues are driving current military needs in basic research leading to emerging *Defense Transformation* goals. The underlying cause of this need for transformation is the dramatic impact computer and information technology has had on training. Within this context we focused our research to address these changed. In particular, due to technological advances, the last few years have witnessed a tremendous increase in machine-delivered training. Computer-based training tools appear to offer a number of advantages over traditional methods: they are relatively inexpensive, they can be used in the field, and they can be programmed to adapt to the learner's performance. However, while this technology offers tremendous promise, it is clear that our understanding of computer-based instruction is currently insufficient to use this technology effectively in many situations and to predict its efficacy and efficiency across training contents and situations. Furthermore, today's digital-age soldiers represent a challenge to military training doctrine in that their life experiences are borne out of the computer age. This has produced a need for understanding of how to most efficaciously present training material to this new group of recruits. The confluence of these events produces the need for a programmatic basic research effort that can disentangle the fundamental issues surrounding learning and performance in the networked battlefield.

As an example of modern training needs, current Air Force operations such as AWACS Weapons Director teams have to manage complex distributed team interactions. These

operational environments have a dynamic mix of cognitive and socio-technical factors that impact performance. These range from synchronous interaction in the absence of co-location, to the multi-sensory nature of systems that require the integration of a variety of perceptual and conceptual knowledge. Information is received from a number of audio and visual sources and this information must be relayed and/or interpreted while communicating with others. In order to avoid problems associated with identification errors, disorientation, and general failures in situation awareness, operators in such environments must have well-developed mental models. These mental models consist of appropriately interlinked concepts associated with their task and task environment. Further, given the team component of their task, individuals in AWACS teams heavily rely upon share mental models of the operational environment.

Our effort is applicable to a number of these issues and we address these problems by analyzing human performance on multiple levels. Generally, in order to appropriately investigate such complex phenomena, and integrate methodologies and issues, a multi-level theoretical approach is required. We have theorized about multiple levels of analysis (i.e., individual factors and team factors) in order to better specify how we conceptualize the complex interaction among constructs. For example, we have articulated how information integration supports successful performance in dynamic team tasks (e.g., Fiore, Cuevas, Scielzo, & Salas, 2002; Scielzo, Fiore, Cuevas, & Salas, 2004). Additionally, we have described how the lack of co-location alters both cognitive factors as well as subsequent team development factors, all of which impact team coordination (e.g., Cuevas, Fiore, Salas, & Bowers, 2004; Fiore, Salas, Cuevas, & Bowers, 2003). In short, our effort articulates how these environments can impinge upon the team processes essential to effective coordination. And, from the cognitive-level, we describe how the integration of critical knowledge components associated with these tasks can attenuate these effects.

CONCLUSION

In the context of learning complex tasks, distributed training may prove more cost-effective because of the dynamic task environments in which Air Force personnel must train and work. Specifically, distributed training designed to facilitate the acquisition of knowledge that is both rich and flexible affords one the ability to accommodate new and complex technology relatively easily. The aforementioned findings provide the foundation on which the Air Force training community may determine how distributed systems can be best designed to account for diversity in trainee aptitude and disposition. Overall, the outcomes of our effort support the AFOSR Mission of providing the best training tools to ensure that the warfighter develops the skills to win. By utilizing an approach that encompasses the organizational and cognitive sciences, we have provided foundational research to the methods for the development and evaluation of warfighter training at the individual and team levels. These include the tools and technologies based upon data-driven empirical efforts and our theoretically-driven organizing frameworks. More generally, this research is foundational to Air Force attempts to identify the type(s) of knowledge and learning strategies most useful for, and most generalizable across, complex tasks and how distributed learning systems may facilitate the development of such knowledge for individuals and teams.

PERSONNEL SUPPORTED and/or ASSOCIATED

Principle Investigators

- **EDUARDO SALAS, Ph.D.,** is a Professor of Psychology at the University of Central Florida and Program Director and Professor for Human Systems Integration Research Department at the Institute for Simulation and Training
- **STEPHEN M. FIORE, Ph.D.,** is Director of the Consortium for Research in Adaptive Distributed Learning Environments, a laboratory that emphasizes interdisciplinary research incorporating aspects of cognitive, social, and organizational psychology in the investigation of learning and problem solving in individuals and groups.
- **CLINT A. BOWERS, Ph.D.,** is Professor of Psychology at the University of Central Florida and Associate Dean of Research for the College of Arts and Sciences at the University of Central Florida.

Graduate Student Support
- Haydee M. Cuevas, UCF Team Performance Laboratory
- Mary Kosarzycki, Institute for Simulation and Training
- Eleni D. Kring, Institute for Simulation and Training
- Sandro Scielzo, UCF Team Performance Laboratory

PUBLICATIONS

Edited Volumes

Bowers, C. A. & Salas, E. (Eds.). (in press). *Teams and technology.* Washington, DC: American Psychological Association.

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Scielzo, S., Cuevas, H. M., & Fiore, S. M. (2004). *Dynamic Distributed Decision-Making: Development of mock-up scenarios for synthetic task environment training* (Technical Report for the Air Force Office of Scientific Research, prepared under Grant Number F49620-01-1-0214). Orlando, FL: University of Central Florida.

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Cuevas, H. M., Scielzo, S., & Fiore, S. M. Evaluating the instructional efficiency of a guided learner-generated questioning strategy within computer-based complex training environments. *Manuscript in preparation.*

Fiore, S. M., Cuevas, H. M., Scielzo, S., & Salas, E. Metacognition and multimodalities: Altering processes and products in distributed learning. *Manuscript in preparation.*

Fiore, S. M., Scielzo, S., Cuevas, H. M., & Salas, E. Working with working memory in complex task training. *Manuscript in preparation.*

Scielzo, S. & Fiore, S. M. A two-stage model of multimedia learning: Implications for multimedia design. *Manuscript in preparation.*

Scielzo, S., Fiore, S. M., & Cuevas, H. M. Multimedia design and redundancy in complex training environments. *Manuscript in preparation.*

Interactions/Transitions

None

New Discoveries

None

Honors/Awards

None

LIST OF APPENDICES

APPENDIX I

Fiore, S. M., Cuevas, H. M., Schooler, J. & Salas, E. (in press). Cognition, teams, and team cognition: Memory actions and memory failures in distributed team environments. To appear in E. Salas & C. A. Bowers (Eds.), *Teams and technology*. Washington, DC: American Psychological Association.

APPENDIX J

Fiore, S. M., Jentsch, F., Bowers, C. A., & Salas, E. (2003). Shared mental models at the intra- and inter-team level: Applications to counter-terrorism and crisis response for Homeland Security. *Proceedings of the 47th Annual Meeting of the Human Factors and Ergonomics Society*, 439-443. Santa Monica, CA: Human Factors and Ergonomics Society.

APPENDIX K

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APPENDIX L

Scielzo, S. & Fiore, S. M. A two-stage model of multimedia learning: Implications for multimedia design. *Manuscript in preparation*.

APPENDIX M

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APPENDIX N

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APPENDIX O

Scielzo, S., Fiore, S. M., & Cuevas, H. M. Multimedia design and redundancy in complex training environments. *Manuscript in preparation*.

APPENDIX P

Kring, E., D. (2004). *Improving metacomprehension and learning through graduated concept model development* (Doctoral dissertation, University of Central Florida, Orlando, 2004).

APPENDIX Q

Cuevas, H. M., Scielzo, S., & Fiore, S. M. Evaluating the instructional efficiency of a guided learner-generated questioning strategy within a computer-based complex training environment. *Manuscript in preparation.*

APPENDIX R
Cuevas, H. M., Fiore, S. M., Bowers, C. A., & Salas, E. (2004). Using guided learner-generated instructional strategies to transform learning into a constructive cognitive and metacognitive activity. *Proceedings of the 48th Annual Meeting of the Human Factors and Ergonomics Society*, 1049-1053. Santa Monica, CA: HFES.

APPENDIX S
Cuevas, H. M. (2004). *Transforming learning into a constructive cognitive and metacognitive activity: Use of a guided learner-generated instructional strategy within computer-based training* (Doctoral dissertation, University of Central Florida, Orlando, 2004).